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CRASH INJURY INVESTIGATION

U. S. ARMY HU-1A

BELL IROQUOIS HELICOPTER ACCIDENT

Fort Carson, Colorado

9 June 1960

FSF

AVIATION CRASH INJURY RESEARCH
A DIVISION OF
FLIGHT SAFETY FOUNDATION, Inc.
2871 SKY HARBOR BLVD. • PHOENIX, ARIZONA

TREC Technical Report 60-72
AvCIR 12-PR-122

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U.S. ARMY HU-1A BELL IROQUOIS HELICOPTER ACCIDENT
Fort Carson, Colorado
9 June 1960

REPORT OF CRASH INJURY INVESTIGATION
For

U. S. Army
Transportation Research Command
Contract DA 44-177-TC-624

AVIATION CRASH INJURY RESEARCH
A Division of
Flight Safety Foundation, Inc.

December 1960

CRASH INJURY INVESTIGATION

Harold F. Roegner- Chief, Investigation Branch
Jack Carroll- Chief, Training Branch

The Crash Injury Analysis and Preparation of this report was accomplished by the above investigators in coordination with the AvCIR staff.

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SUMMARY

A U.S. Army HU-1A Bell helicopter crashed at 1105 hours on 9 June 1960 while on a tactical mission. The crash site was in a mountainous area on the Fort Carson Military Reservation near Butts Army Airfield, Fort Carson, Colorado.

One crew member and three passengers were aboard the aircraft at the time of the accident. The pilot and the occupant in the copilot's seat sustained spinal strains while the other two occupants received strains, abrasions, and cuts. (AvCIR Scale of Injuries is contained in Appendix III)

A crash injury investigation of the accident was conducted on 11-12 June 1960 by Aviation Crash Injury Research (AvCIR) under the provisions of U.S. Army Transportation Research Command Contract No. DA 44-177-TC-624. The aircraft was examined at the crash site, and photographs of the wreckage and of all essential components and equipment were obtained during the course of the investigation.

This investigation revealed that the injuries experienced by the occupants resulted from vertical deceleration, failure of the troop seat, and failure of the transmission support, permitting displacement of the transmission into the cabin of the aircraft through the rear bulkhead. The side and the rear roof support members failed in this accident in a manner almost identical to failures of these parts experienced in other HU-1A helicopter accidents. The accident also revealed the excellent energy absorption characteristics of the skid landing gear and the crew seat cushion.

Statements of the pilot and passengers and information from the Fort Carson Accident Board assisted the investigation team in estimating the flight path velocity, impact conditions, and the principal vertical and horizontal forces during the crash.

This is the final report on the crash injury investigation.

Figure 1. Photograph of HU-1A in flight

DESCRIPTION OF THE ACCIDENT

CRASH SEQUENCE

A U.S. Army HU-1A Bell "Iroquois" helicopter engaged in the transportation of personnel from Butts Army Airfield, Fort Carson, Colorado, crashed during an attempted landing at 1105 hours on 9 June 1960. The intended landing site was the combat field range at Fort Carson Military Reservation (elevation 6560 ft. m. s. l) approximately 9 miles southwest of Butts Army Airfield, Fort Carson, Colorado. (Figure 2 is an aerial view of the accident scene.)

Figure 2. Aerial view showing the flight path, intended landing site and crash site.

As the pilot was making an approach to his intended landing site on the reservation, he noted obstructions and immediately initiated a climbing turn to the right. After completing approximately 270 degrees of the turn at an altitude of 300 feet, a partial power failure occurred. The pilot immediately actuated the increase power switch. Power increased momentarily and then decreased to between partial and full loss of power. The pilot then lowered the nose of the aircraft, entered autorotation, and committed the aircraft to a forced landing. Upon entry into autorotation, the pilot noted a very steep angular approach and an unusually high rate of descent. Just prior to the crash, he succeeded in reducing this high "sink rate" by one-half, or to approximately 2000 feet per minute, and then executed a full flare.

During the full flare, the main rotor blades contacted a large pine tree causing sudden stoppage of the rotor system as the aircraft forcibly contacted the ground. The principal impact forces were absorbed by the skids as the aircraft impacted the terrain against a 20 degree upslope.

The kinematic behavior of the aircraft during the crash is shown in Figure 3.

EVACUATION

The pilot's cockpit door (right side) was torn free at impact as was the right cabin door. The copilot's door was thrown open at impact and the left cabin door was partially dislodged from the track supports. Both pilot and copilot released themselves and evacuated through their respective doors without difficulty. The left cabin occupant released himself and evacuated through the left cabin door; the right cabin occupant, having fallen to the cabin floor through the broken seat, released himself and evacuated through the right cabin door.

As a matter of interest, there are no instructions on the exterior of the cabin doors, or surrounding area, regarding their operation. It must be remembered that the crew compartment doors are hinged and open outward, whereas the cabin doors slide fore and aft on tracks. On several occasions, around intact aircraft, it has been noted that the cabin doors were pulled in the same manner as the cockpit doors. This could prove to be time consuming in the event of a post-crash fire if the rescue personnel were not familiar with its direction of operation. The interior is placarded with a direction arrow and the word "pull" for the benefit of the occupants. It is suggested that unmistakable door operating instructions be placed on the exterior near the operating handle.

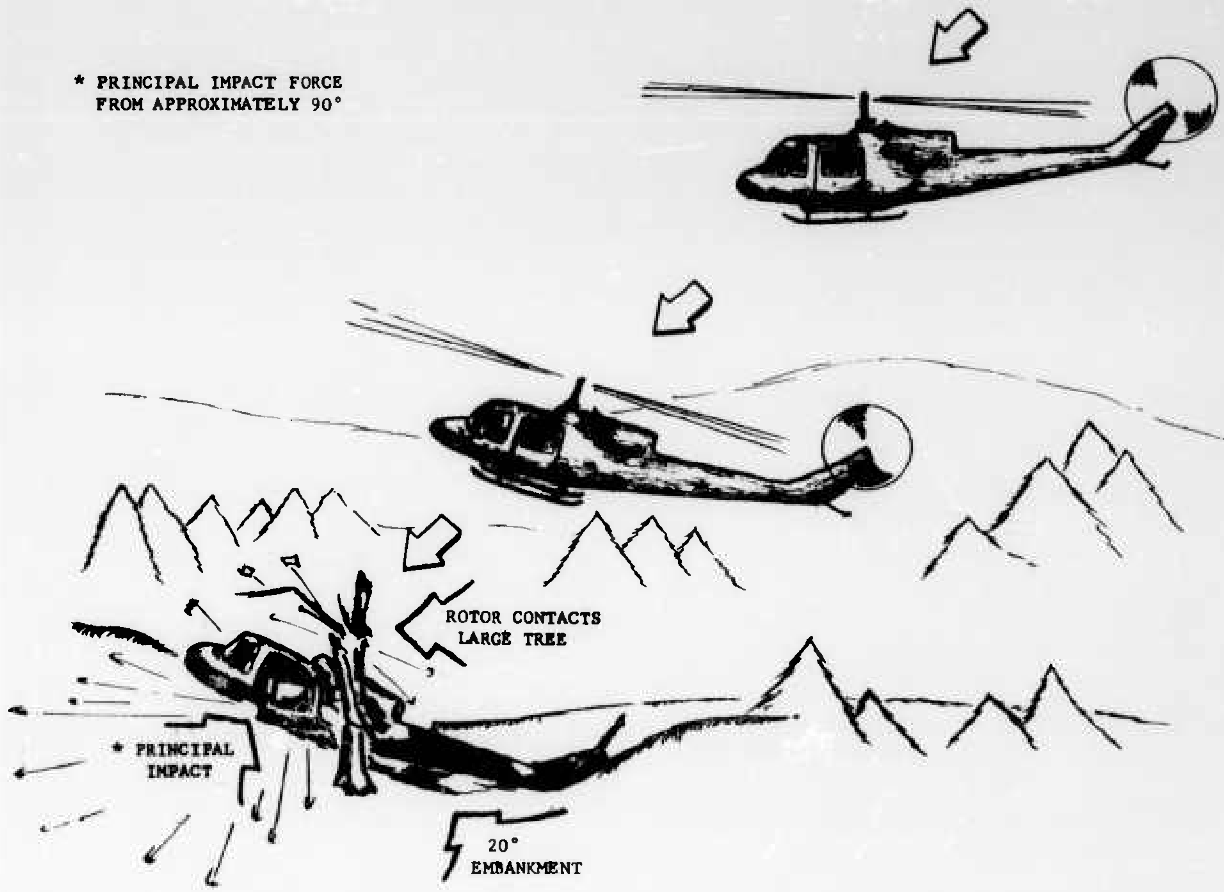


Figure 3. Kinematic drawing of the crash sequence

CRASH FORCES

A complete analysis of the crash forces involved in this accident is contained in Appendix I. The analysis revealed that the mean crash force resultant was relatively moderate. Based upon the information available, it is computed that the forces were approximately 13 G on the aircraft from approximately 90°.

DAMAGE TO THE AIRCRAFT

EXTERIOR

Damage to the cockpit and cabin areas of the fuselage consisted primarily of compression distortion to the underside of the main cabin, failure of the vertical side supports, failure of the aft bulkhead and penetration of the aft bulkhead by the transmission assembly. Additional damage consisted of distortion on the left side at the cockpit door, broken left windshield and center windshield braces, tail boom distortion at the attachment points, and extensive rotor blade damage. Figures 4 through 7, taken at the crash site, depict overall damage.

Figure 4. Front view of the helicopter showing broken plexiglas in both pedal wells and left windshield. Destruction of the main rotor is clearly shown.

Figure 5. Side view of aircraft showing embankment struck with relative position of pine tree.

Figure 6. Right front view of the helicopter. Note the distorted right skid.

Figure 7. Rear view of helicopter showing demolished rotors and twisted tail boom.

A discussion of the most significant damage from a crash injury point of view follows:

Transmission Assembly

The transmission assembly failed in this accident in the same manner as experienced in previous HU-1A accidents. The significant failure point in all HU-1A accidents is the magnesium casting which serves as a cradle supporting the transmission assembly. In this instance, the transmission moved forward and was, therefore, a contributing factor insofar as injuries are concerned. This is a hazard which has been pointed out on several occasions. During a recent evaluation of the HU-1D helicopter, it was found that Bell Aircraft was providing for a fifth transmission mount to prevent the transmission from moving forward during a crash. It is questionable, however, whether this will resolve the problem because the failures have not occurred at the mounts, but rather in the magnesium casting which serves as a cradle for the transmission assembly. The failure experienced in this accident is shown in Figure 8.

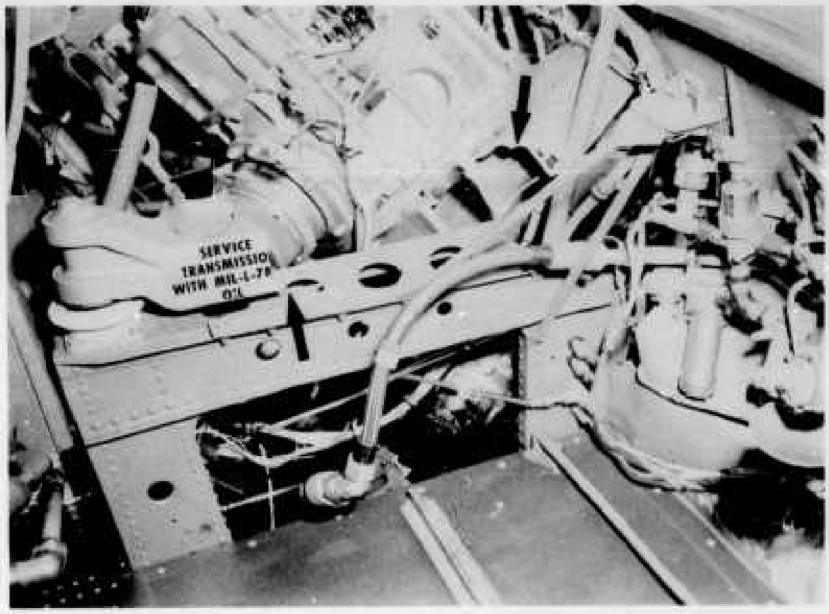


Figure 8. Note the fractures in the magnesium casting (arrows).

Side and Rear Roof Supports

The overhead structure of the HU-1A is supported by two side vertical support members just aft of the pilot and copilot seats, and by the rear bulkhead separating the cabin section from the transmission and support assembly. The side and rear roof supports failed in this accident in the same manner as experienced in four other HU-1A accidents. In this accident, however, the roof structure did not move forward and downward into the occupied area of the cabin, as experienced in some of the other cases. This is attributed to the fact that there were negligible longitudinal forces involved at impact. Failures of these support members are shown in Figures 9 through 18.

Failure of these support members in this and four other HU-1A accidents reported indicates an inherent structural weakness and stresses the need for redesign to eliminate this potentially dangerous crash injury hazard.

Figure 9. Side view showing failure of left vertical support at upper attachment and shifting of overhead cabin structure.

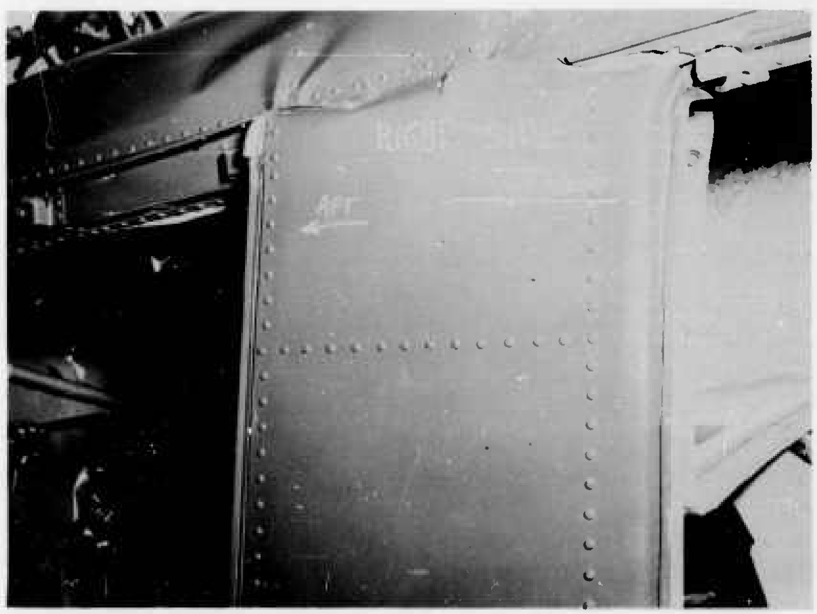


Figure 10. Side view showing failure of right vertical support at upper attachment and shifting of overhead cabin structure.

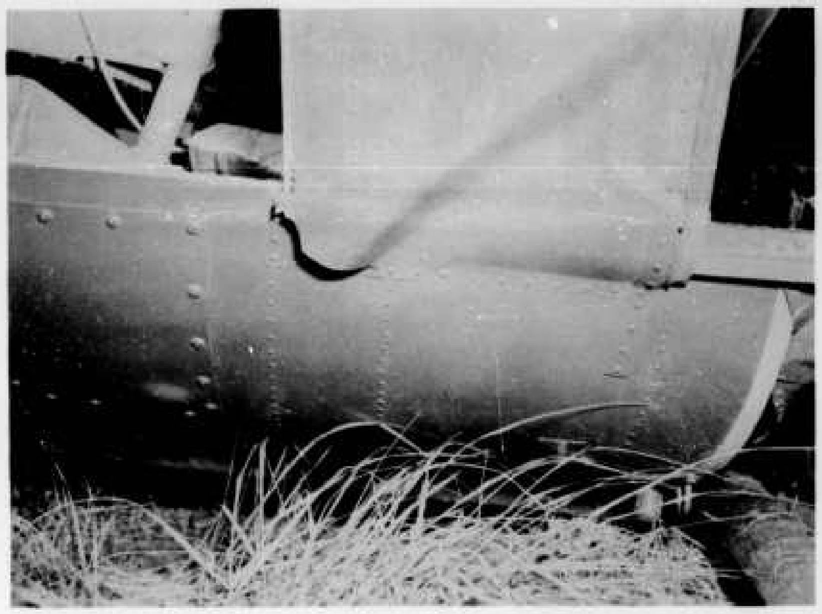


Figure 11. Side view showing distortion and impending separation of left vertical support at lower attachment.

Figure 12. Side view showing distortion and impending separation of right vertical support at lower attachment.

Figure 13. The arrow depicts the separation of the right vertical side support from its attaching point, floor level.

Figure 14. View of left vertical support at floor showing failure and impending separation at attaching point.

Figure 15. The arrows depicts the failures at the top of the right vertical side support.

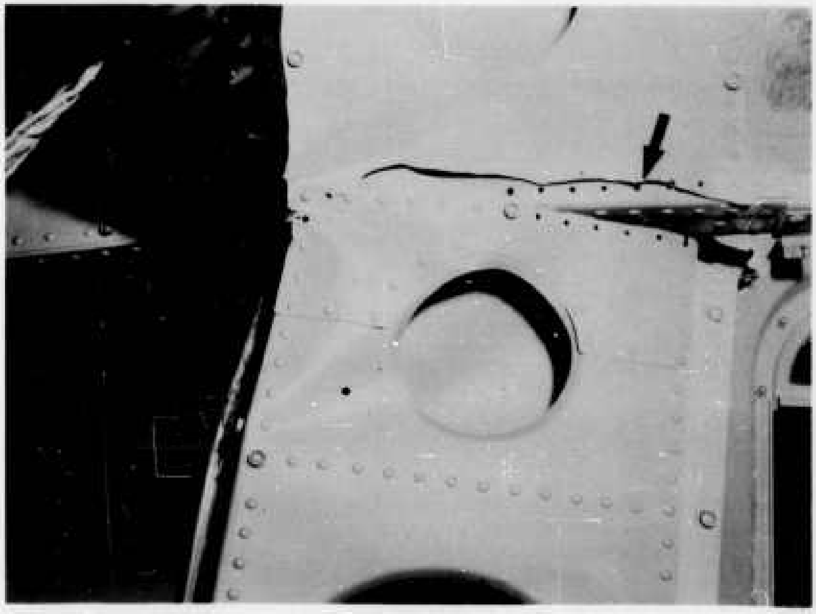


Figure 16. The separation of the left vertical side support and roof structure is denoted by the arrow.

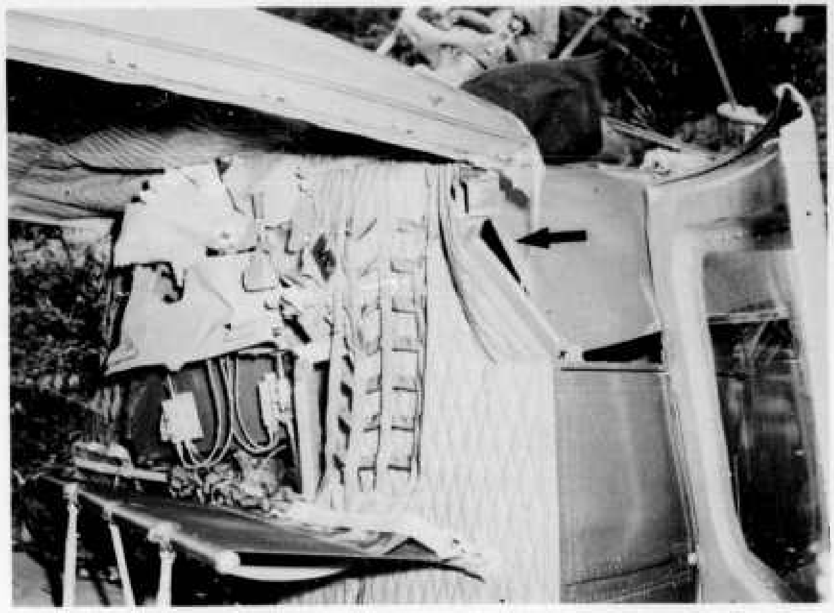


Figure 17. The forward displacement of the firewall, left side, is depicted by the arrow.

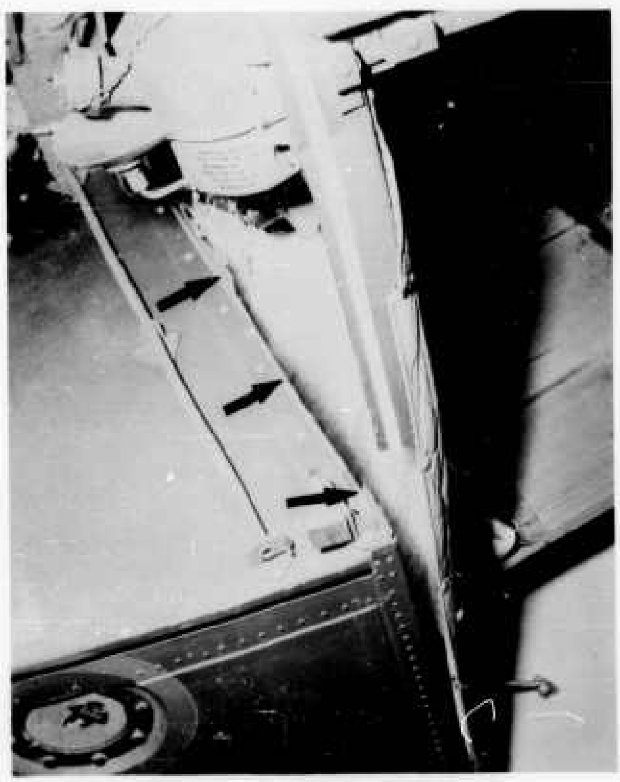


Figure 18. Rear view of the right side showing the firewall displacement (arrows). It should be noted that there was very little forward deceleration in this accident.

The Bell Helicopter Corporation is aware of these problems and has submitted the following solutions in response to RFA studies requested by the Army:

"RFA #11 requested that the contractor study the aft cabin bulkhead to improve the structure. As a result of these studies, the contractor is of the opinion that the most logical approach to improving the strength of this bulkhead would be to change the structure above W. L. 54 to a honeycomb type structure. In order to effect this change, it would be necessary to make extensive tooling changes, such as fabrication of a bonding fixture, and to re-engineer the mounting of those items such as hydraulic and electrical equipment which are attached to the bulkhead. By changing the sheet metal structure to honeycomb type construction, the pure vertical load carrying capability of the bulkhead would be increased from 14,900 lbs. to 35,000 lbs. It should be noted that these are comparative figures only and do not take into account lateral or fore and aft displacement of the bulkhead under crash loading conditions. Displacement of the bulkhead would materially reduce the vertical load capability of the bulkhead; therefore, the true crash load capabilities of the bulkhead cannot be calculated.

RFA #12 requested that the contractor study the problem of adding vertical support members to prevent collapse of the roof structure upon occupants during a crash landing of survivable "G" forces. As a result of these studies, it is the opinion of the contractor that the most logical approach would be one of making a general increase of gauge thickness of the sheet metal structure of the door post to increase its column load capabilities. The weight increases per helicopter would be approximately 3.5 lbs. The column strength would increase from 1750 lbs. to 2690 lbs. per door post for a total increase in strength of approximately 54%. This change could be accomplished on production HU-1B's and does not involve serious tooling problems. A second approach which the contractor investigated was the addition of roll-over structure to the pilot and copilot seats. This change would add approximately 3. 5 lbs. per helicopter and would provide structure capable of withstanding a vertical load of 3500 lbs. per seat. This change could be incorporated into production aircraft or retrofitted to aircraft already built with changes to the seat assembly."

Information has become available that the recommendations submitted by Bell Helicopter Company under RFA #12 have been approved and are being incorporated in all HU-1B helicopters and that the recommendation

submitted under RFA #11 has also been approved and that the new rear support member is being incorporated in HU-1B helicopters beginning with ship #47. These modifications are expected to eliminate the problem of the roof collapsing into the occupiable area in HU-1B helicopters; however, this potentially dangerous situation still exists in all HU-1A helicopters in the system. A solution to this problem would be the acceptance of the second approach submitted in the Bell study under RFA #12 involving the addition of roll-over structure to prevent the roof from collapsing down onto the seat backs.

Skid Gear

The skid type landing gear consists of two lateral mounted arched cross tubes attached to formed, longitudinal skid tubes. The gear assembly is attached with clamps at four points of the fuselage structure. The two cross tubes act as energy absorbers and their efficiency has been proven in the majority of accidents investigated by this organization. The location of the cross tubes and the inner action effects peculiar to this gear provide a nearly equal distribution of landing loads between the cross tubes for all level attitudes. This is an efficient energy absorption feature. The effectiveness of this gear can be seen in Figures 19 and 20.

Figure 19. Left side view of aircraft showing displacement of the left forward cross tube and distortion to underside of the main cabin.

Figure 20. Note the manner in which the landing skid has deformed to fit the contour of the hill.

INTERIOR

Relatively minor damage was experienced in the cockpit area during impact. The damage consisted primarily of a broken left windshield, broken plexiglas in both pedal wells and slight forward displacement of the instrument panel. The pilot and copilot seats remained intact and safety belts and shoulder harnesses were effective. Figure 21 illustrates the intact condition of the cockpit section.

The most severe damage to the interior section of the aircraft was experienced in the cabin section. Failure of the troop seat and penetration of the rear bulkhead by the transmission are significant from a crash injury point of view. Figure 22 shows the seating arrangement, injuries sustained by the occupants, and damage to the interior of the aircraft.

Sudden stoppage of the rotor when it contacted the tree, plus the vertical forces, resulted in failure of the transmission support casting and caused the lower end of the transmission to rip through the rear bulkhead into the cabin area a distance of 17-inches. As shown in Figure 22, the transmission entered the cabin at an angle toward seat R-1, which was occupied. The occupant of seat R-1 advised that he was wearing his safety belt extended to its maximum length at the time of impact. At impact the front seat support tube of seat R-1 failed. Failure of the front seat support

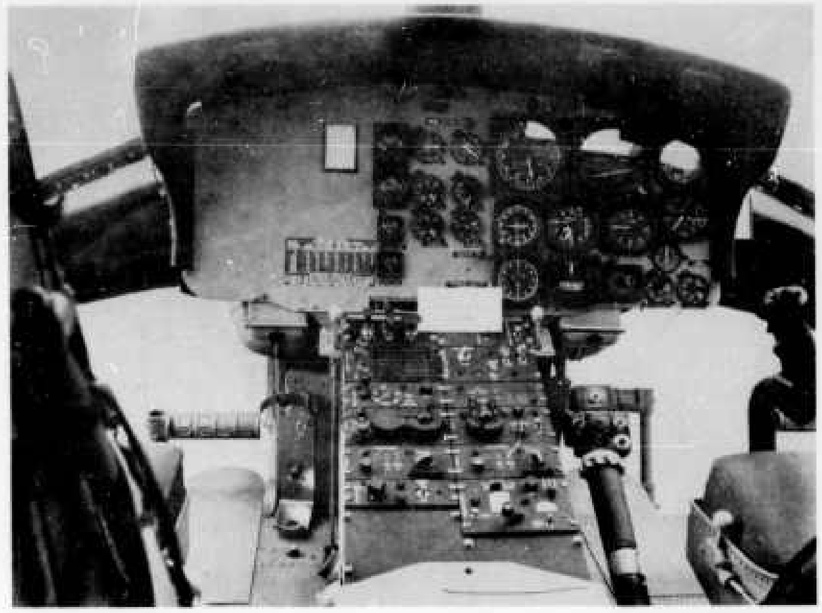


Figure 21. The intactness of the cockpit is depicted in this photo. The fire extinguisher was removed after the accident.

tube coupled with the extreme slack in the occupant's seat belt permitted him to move forward and downward, away from the transmission as shown in Figures 23 and 24. This fortunate coincidence probably prevented dangerous or fatal injuries to the occupant. Jagged and torn metal caused by penetration of the transmission is shown protruding into the cabin area in Figure 25.

In addition to failure of the front seat support tube, the seat back upper attachment of seat R-1, which is attached to the firewall by means of four bolts inserted through drilled holes in the attachment, also failed, Figure 26. This attachment supports the seat back webbing. Failures frequently occur at these weakened points under relatively low crash forces. It appears that a clamp type attachment similar to that which supports the rear seat support beam in the HU-1A, would be more satisfactory. It is obvious that a considerable load was imposed on this support by the transmission failure; however, numerous failures of this type seat have been noted in other accidents in which the transmission was not a factor.

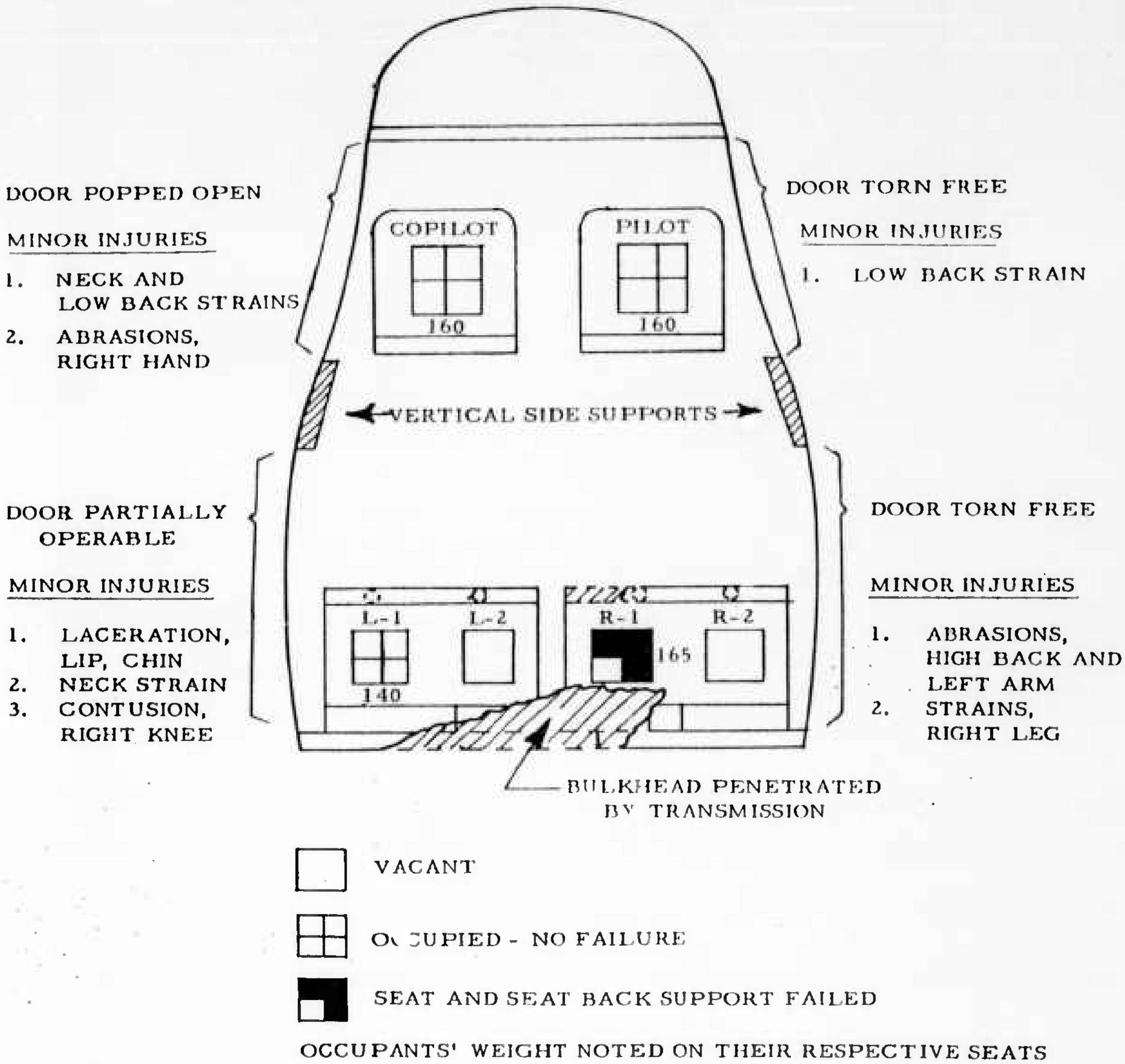


Figure 22. Seating arrangement, seat damage, and injuries.

Figure 23. Posed photograph from right side of aircraft shows final position of occupant and penetration of aft cabin bulkhead by transmission assembly (see arrow) and its relation to occupant.

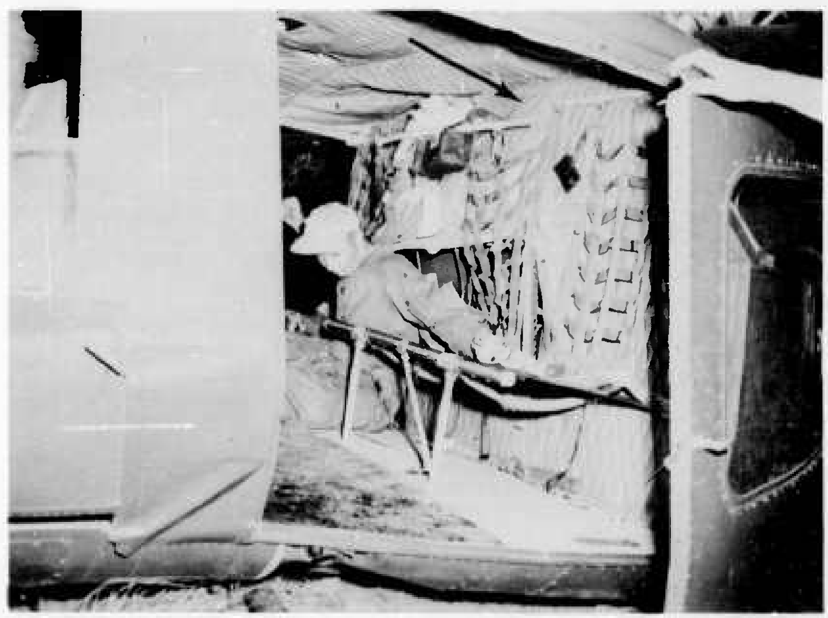


Figure 24. Posed photograph from left side of aircraft shows final position of occupant and broken seat back upper attachment (arrow).

Figure 25. The 17-inch forward displacement of the transmission should be noted in this side view. The forward displacement of the firewall is also visable. The fracture in the floor occurred at the outboard edge.

Figure 26. Arrow 1 depicts the broken front seat tube. This failure permitted the occupant to be thrown onto the cabin floor. Arrows 2 and 3 point out the fractures in the seat back upper attachment.

Figure 27. Arrow 1 denotes the desirable safety belt attachment. Arrow 2 depicts the manner of attachment which is normally utilized.

An additional item of interest is depicted in Figure 27. Arrow 1 points out a short length of cable which is anchored to primary structure. These cables are installed at intervals across the aft bulkhead and are intended to serve a two-fold purpose: (1) to anchor the ferry tank when utilized and;(2) to function as a safety belt attachment when transporting troops. The utilization of these cables relieves the rear seat support beam of a considerable load and also properly positions the safety belt across the hips at approximately a 45° angle. This desirable 45° angle places a majority of the load on the hips and forces the spine to flex at the lumbo-sacral joint. When the safety belt is attached to the "O" ring as shown in Figure 27, Arrow 2, the safety belt crosses the occupant at approximately a 90° angle and forces the spine to flex in a higher area, often causing flexion fractures. It is therefore suggested that all safety belts in the cabin be attached to the cables to afford the occupant maximum protection.*

*This item has been reported in a Crash Injury Bulletin, TREC Tech Report 60-61, AvCIR Report No. 69-0-120.

CRASH INJURY ANALYSIS

GENERAL

The direction of the principal crash force was from approximately 90° below the longitudinal axis of the aircraft. The flight path angle was approximately 70° , in relation to the horizontal, as the aircraft contacted the tree and the side of a 20° upslope, resulting in high vertical deceleration and a minimum of longitudinal deceleration. This is substantiated by the relatively short distance the roof structure shifted forward during the crash.

COCKPIT

Pilot

The pilot who was utilizing his APH-5 helmet, safety belt and shoulder harness, was forced downward and forward at impact and sustained a minor injury consisting of a low back strain. The shoulder harness and safety belt functioned properly. The injury can be attributed to vertical forces.

Copilot

Since the occupant was not a crew member he did not have an APH-5 helmet. The safety belt and shoulder harness functioned properly. The injuries sustained consisted of strains in the neck and lower back, plus abrasions on the right hand. The strain to the neck and lower back are attributed to vertical force. The abrasions on the right hand were caused by striking either the radio console or the instrument panel.

CABIN

Seat L-1

At impact, the occupant of this seat flexed forward sufficiently to strike his right knee with his chin which caused lacerations to the lip and chin, and a contusion to the right knee. He also experienced a strain in the neck which can be attributed to the forward flexing of the head. The safety belt functioned properly. Shoulder harness and crash helmets are not provided for passengers in this aircraft.

Seat R-1

At impact, the occupant of this seat received abrasions to the back and left arm which were inflicted by the jagged metal from the transmission and rear bulkhead. He also experienced leg strains attributable to failure of the seat. The absence of more severe injuries is due to the occupant wearing a

safety belt extended to its maximum length and the failure of the front seat support tube. The maximum extension of the safety belt allowed the occupant to move forward during the deceleration while the broken support tube permitted him to bottom onto the cabin floor. This forward and downward movement prevented the transmission from inflicting dangerous or fatal injuries.

CONCLUSIONS

After examination and analysis of the wreckage and injuries sustained by the occupant, it is concluded that:

1. The landing skids and cross tubes absorbed a considerable degree of crash energy;

2. The side and rear roof support members will not support the roof of this aircraft under conditions of survivable crash forces;

3. The design requirements for troop seats as specified in MIL-S-5804B offer the occupant inadequate crash protection. Past accident experience underlines this deficiency;

4. Inadequate support for the transmission constitutes a serious hazard for the occupants occupying the troop seats;

5. The safety belts would afford the occupants more protection if they were attached to the cables provided for this purpose; and

6. The operation of the cabin doors could be expedited if unmistakable operating instructions were utilized.

RECOMMENDATIONS

Based on the foregoing conclusions, it is recommended that:

1. Consideration be given to the installation of a suitable roll-over structure in all HU-1A aircraft to prevent the roof structure from collapsing downward into the occupied area of the aircraft;

2. The present troop seat specifications be subjected to realistic appraisal in order to determine what steps can be taken to increase occupant protection;

3. The design of the transmission support structure be revised to prevent failure and displacement of the transmission into the occupiable area of the cabin;

4. The safety belts in the cabin area be attached to the cables provided to afford the occupant maximum protection; and

5. Unmistakable door operating instructions be placed on the exterior of the aircraft in order to eliminate any delay of entry by rescue personnel in the event of post-crash fire.

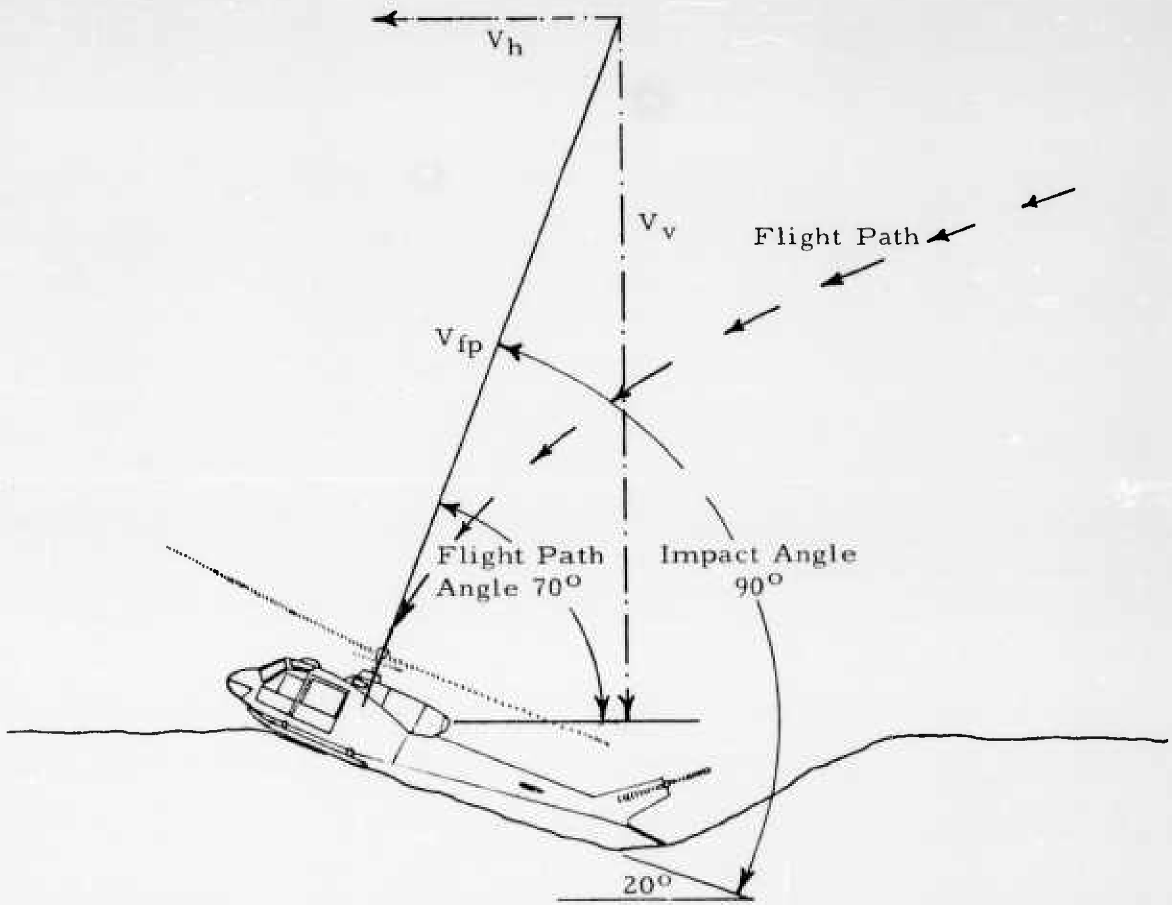
APPENDIX I

CRASH FORCE ANALYSIS

CRASH FORCE ANALYSIS

GENERAL DATA

The following illustration presents a graphic description of flight path, terrain, impact angle, stopping distances, velocities, etc.



The most reliable estimate of velocity at the instant of impact was the rate of descent. The investigation determined this to be in the order of 2000 feet per minute (V_v - vertical velocity = 2000 ft./min).

Analysis at the scene of the accident also afforded these following data:

Terrain angle: 20° upslope

APPENDIX I

Attitude at impact: Pitch - 20^{o} up; Roll - 0^{o}; Yaw - 0^{o}

Stopping distances:

Vertical (S_v) (With reference to imaginary horizontal)		
in aircraft structures	1.3 ft.	1.4 ft.
in ground	0.1 ft.	
Horizontal (S_h)		
in aircraft structures	0.5 ft.	0.512 ft.
in ground	0.012 ft.	
In direction of impact (S_r)		
in aircraft	1.4 ft.	1.5 ft.
in ground	0.1 ft.	

Flight Path Angle: 70^{o} (At instant of impact)

Impact Angle: 90^{o}

ANALYSIS

The velocity of the aircraft (along the flight path - at the instant of impact) may be considered to be the resultant of vertical and horizontal components of velocity.

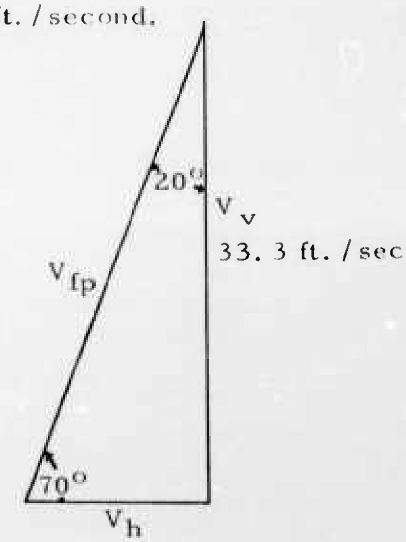
As the vertical component of velocity is assumed to be in the order of 2000 feet per minute, the flight path velocity (V_{fp}) may be calculated:

Rate of descent (V_v) = 2000 ft./minute = 33.3 ft./second.

$$\text{Cos } 20^{o} = \frac{33.3}{V_{fp}}$$

$$.940\, V_{fp} = 33.3$$

$$V_{fp} = 35.4 \text{ ft./second}$$



The acceleration, primarily perpendicular to the longitudinal axis of the aircraft, (mean resultant G force) in this case, may be estimated directly from the entrance and exit flight path velocity (V_{fp}), and the resultant stopping distance (S_r). Horizontal and vertical acceleration components occurred simultaneously.

Acceleration

$$G_r = \frac{V^2 fp - V_o{}^2 fp}{64\, S_r} = \frac{0 - (35.4)^2}{64 \times 1.5} = 13\ G_r$$

Duration

$$t = \frac{V - V_o}{a} = \frac{0 - 35.4}{32 \times 13} = 0.085 \text{ sec.}$$

Rate of Onset

$$R.O. = \frac{2\,G}{t} = \frac{2 \times 13}{0.085} = 300 \text{ G/sec}$$

Direction

All positive acceleration; perpendicular to the longitudinal axis of the aircraft (90^{o}).

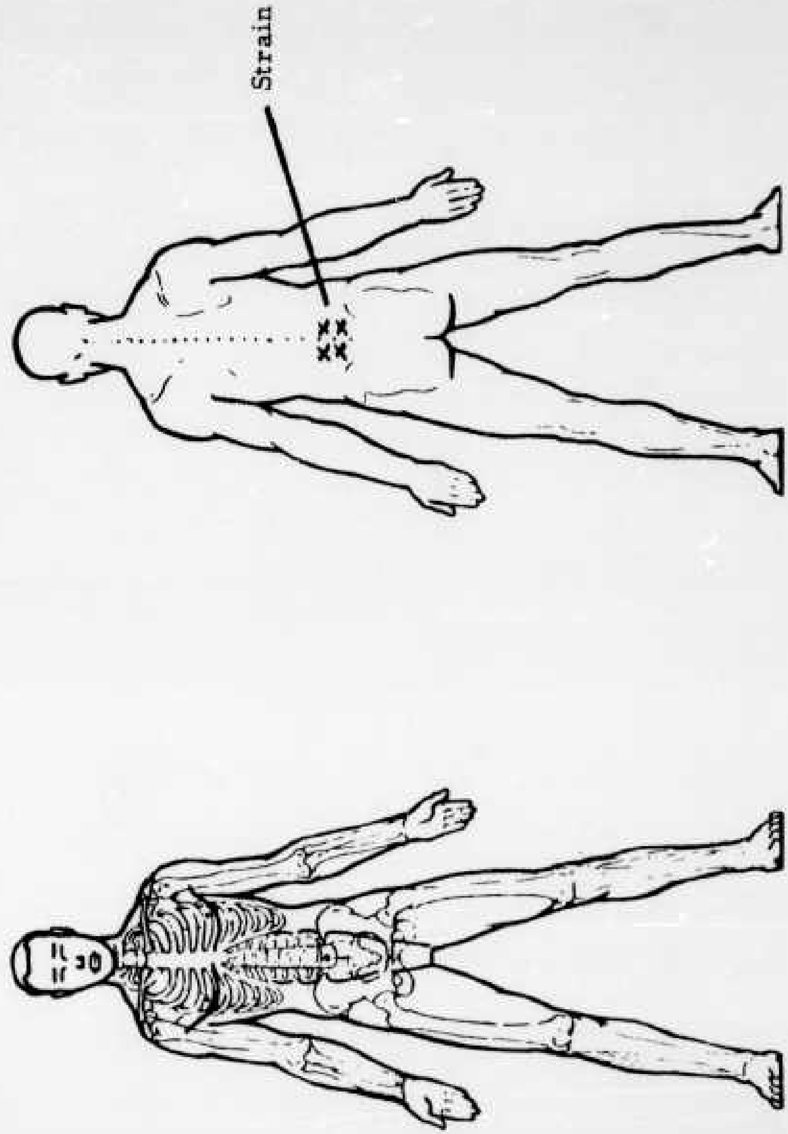
CONCLUSIONS

It is concluded that the crash force experienced at the reasonably intact floor level of the aircraft was in the order of 13 G, 0.085 sec. at 300 G/sec.,applied vertically (positive).

APPENDIX II

MEDICAL SUMMARIES

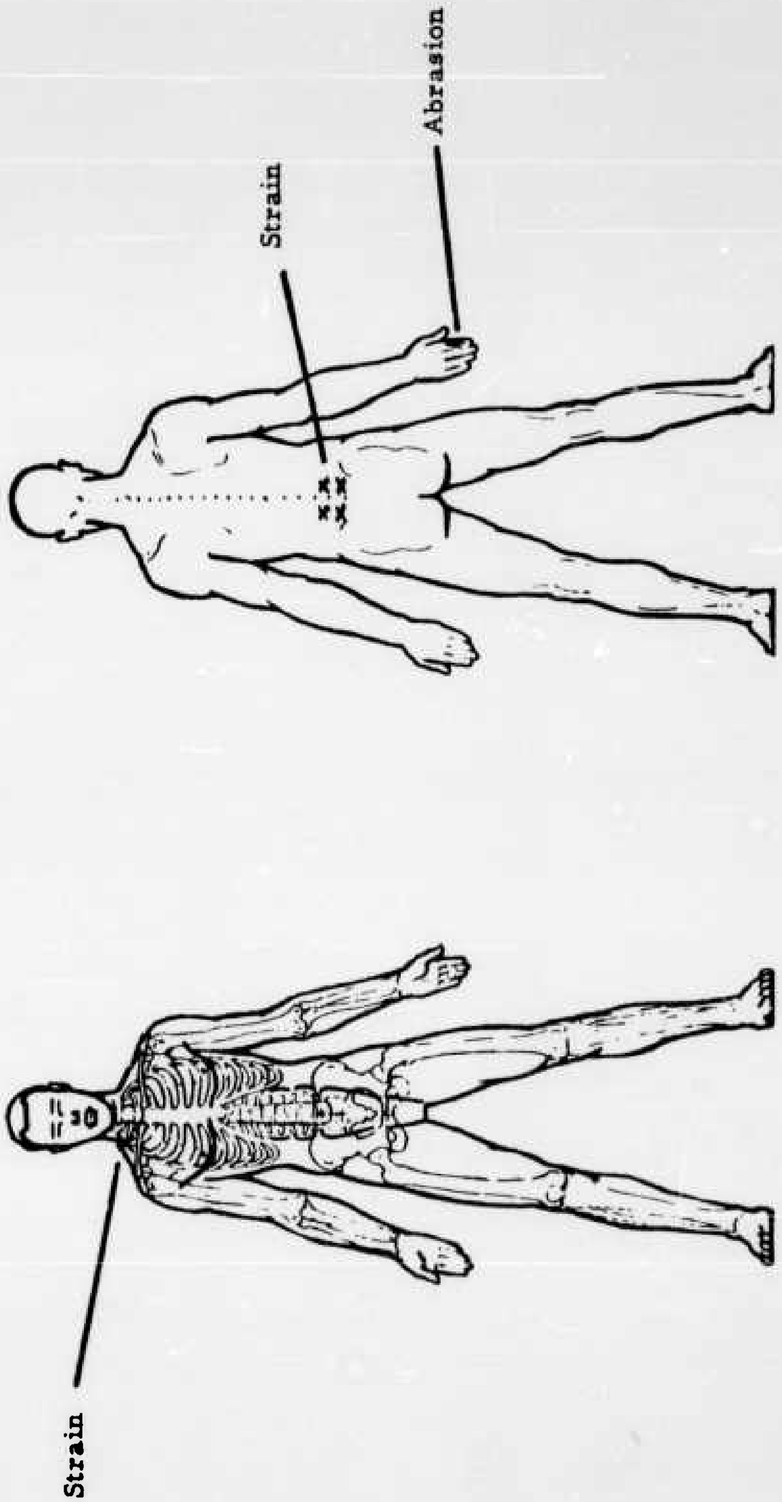
PILOT



Age 32 Height 6'0" Weight 160

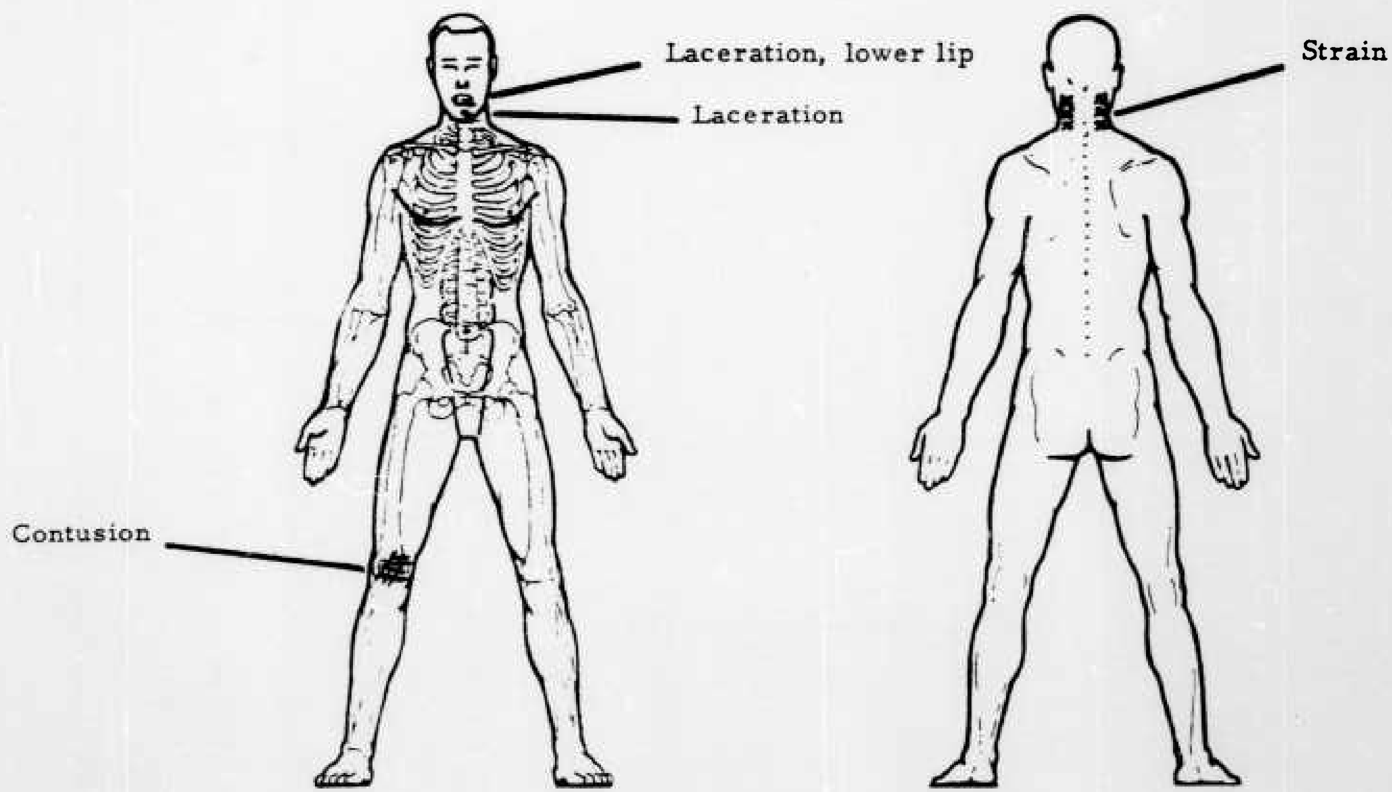
APPENDIX II

PASSENGER IN COPILOT SEAT



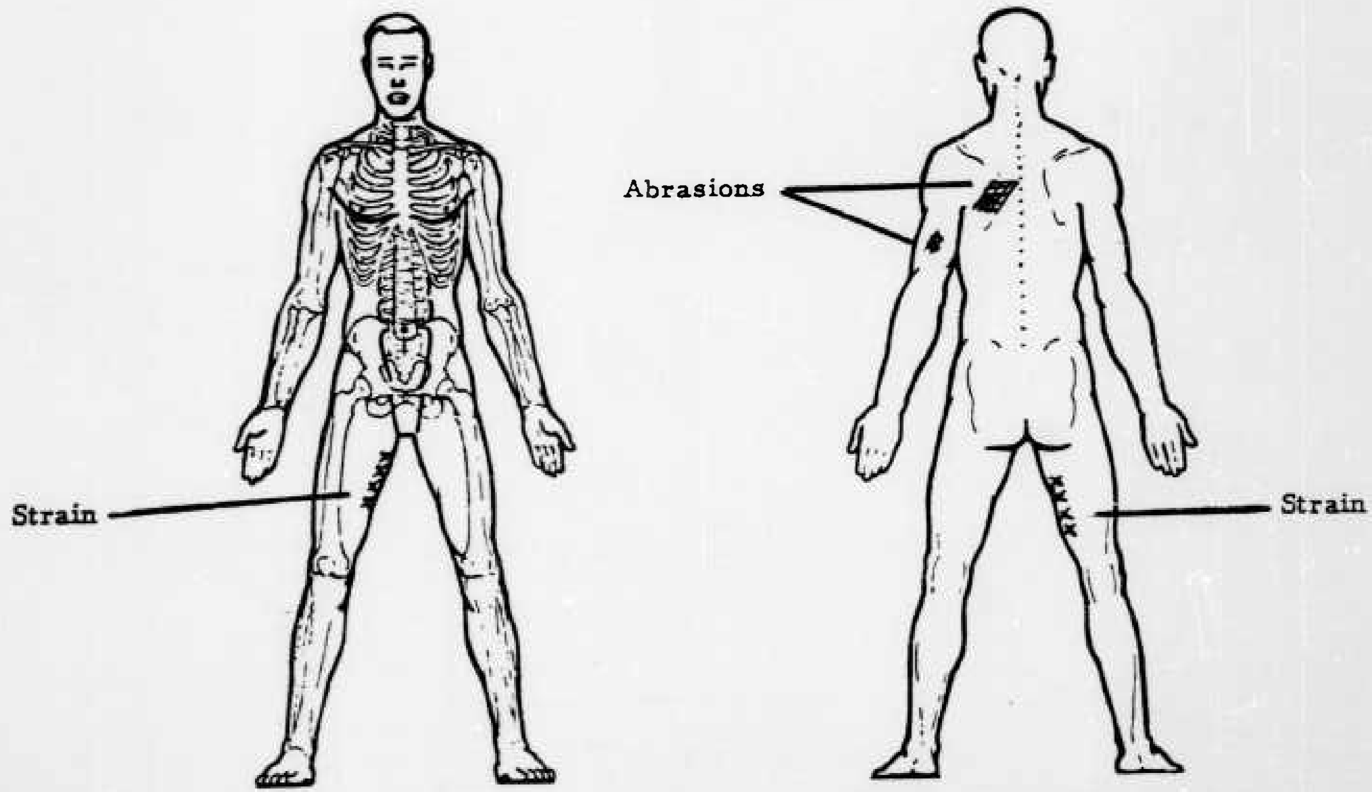
Age 33 Height 5'7" Weight 160

SEAT - L 1



Age 37 Height 5'9" Weight 140

SEAT - R 1



Age 27 Height 5'8" Weight 165

APPENDIX III

AvCIR SCALE OF INJURY

SCALE OF INJURY* USED BY AvCIR

(Revised 4/60)

Degree of Injury	Classification and Description of Injury
None or Trivial	No Injury - Abrasions or scratches of a superficial nature.
Minor	"Minor" contusions, lacerations, abrasions in any area(s) of the body. Sprains, fractures, dislocations of fingers, toes, or nose. Dazed or slightly stunned. Mild concussion as evidenced by mild headache, with no loss of consciousness.
Moderate	"Moderate" contusions, lacerations, abrasions in any area(s) of the body. Sprains of the shoulders or principal articulations of the extremities. Uncomplicated, simple, or green-stick fractures of extremities, mandible and rib cage (excluding spine). Concussion as evidenced by loss of consciousness not exceeding 5 minutes, without evidence of other intracranial injury.
Severe (survival normally assured with prompt medical care and without complications)	Extensive lacerations without dangerous hemorrhage. Compound or comminuted fractures, or simple fractures with displacements. Dislocations of the arms, legs, shoulders or pelvisacral processes. Fractures of the facial bones excluding mandible. Severe sprains of the cervical spine. Fractures of transverse and/or spinous processes of the spine, without evidence of spinal cord damage. Fractures of vertebral bodies of the dorsal and/or lumbar spine, without evidence of spinal cord damage, or compression fractures of L-3-4-5 without evidence of damage to nervous system. Skull fracture without evidence of concussion or other intracranial injury. Concussion as evidenced by loss of consciousness of over 5 and up to 30 minutes, without evidence of other intracranial injury.
Serious (but survival probable)	Lacerations with dangerous hemorrhage. Fractures or dislocations of vertebral bodies of the cervical spine, without evidence of spinal cord damage. Compression fractures of vertebral bodies of dorsal spine and/or of L-1 and L-2 without evidence of spinal cord damage. Compression fractures of L-3-4-5 with

*Based on observations during first 48 hours after injury and previously normal life expectancy.

Degree of Injury	Classification and Description of Injury
Serious (cont'd)	evidence of damage to nervous system. Crushing or multiple fractures of the extremities and/or of the chest. Indication of moderate intrathoracic or intra-abdominal injury. Skull fracture with concussion as evidenced by loss of consciousness up to 30 minutes. Concussion as evidenced by loss of consciousness of over 30 minutes to 2 hours, without evidence of other intracranial injury.
Critical (survival uncertain or doubtful. Includes fatal termination beyond 24 hrs.)	Evidence of dangerous intrathoracic or intra-abdominal injury. Fractures or dislocations of vertebral bodies of cervical spine with evidence of cord damage. Compression fractures of vertebral bodies of dorsal spine, and/or L-1, L-2, with evidence of spinal cord damage. Skull fracture with concussion as evidenced by loss of consciousness beyond 30 minutes. Concussion as evidenced by loss of consciousness beyond 2 hours. Evidence of critical intracranial injury.
Fatal within 24 hrs. of accident	Fatal lesions in single region of the body, with or without other injuries classed as Severe.
Fatal within 24 hrs. of accident	Fatal lesions in single region of the body, with other injuries classed as Serious or Critical.
Fatal	Fatal lesions in two regions of the body, with or without other injuries elsewhere.
Fatal	Fatal lesions in three or more regions of the body - up to and including demolition of the body.

APPENDIX IV

SUMMARY OF CRASH SAFETY CRITERIA

SUMMARY OF CRASH SAFETY CRITERIA

In its efforts to determine the crash survival aspects of aircraft accidents AvCIR, a Division of the Flight Safety Foundation, is guided by certain criteria which it considers fundamental for the crash protection of aircraft occupants. The same criteria are also used to evaluate the crash safety features of mock-ups and prototypes.

CRASHWORTHINESS

Crashworthiness may be defined as the ability of basic aircraft structure to provide protection to occupants during survivable impact conditions. Impact conditions are considered survivable in that part of the cockpit/cabin area where the crash forces are within the limits of human tolerance (with minimal or no injury)* and where surrounding structure remains reasonably intact.

Lack of crashworthiness, generally, indicates that the basic aircraft structure, seen as a protective container, is subject to extensive inward collapse thereby affecting the "inhabitability" of this area. Typical in this respect are (1) the rearward movement of the engine in single engine aircraft; (2) the downward displacement of transmissions and other heavy components in helicopters; (3) the upward collapse of lower structures into the cockpit/cabin area. This deformation or collapse of the occupiable area may result in crushing type injuries or trapping of the occupants.

When evaluating the crashworthiness of basic aircraft structure, stress is placed upon the expected behavior of this structure during a survivable type impact. Attention is also given to anticipated dynamic response under the most probable conditions of impact angle and aircraft attitude, based upon accumulated past experience. This facilitates an appraisal of the possibility of displacement of certain heavy components into the occupiable area as a result of inertia forces.

TIE-DOWN CHAIN

Although a crashworthy structure provides primary protection during a crash deceleration, injuries may still occur when occupants are allowed to come into forceful contact with their environment or to be struck by loose objects thrown through the occupiable area. The restraint system used to prevent occupants, cargo and components from being thrown loose within the aircraft is commonly referred to as the tie-down chain. The occupant's tie-down chain consists of: seat belt, seat belt anchorage, shoulder harness and anchorage, seat structure, seat anchorages and floor. Failure of any link in this chain results in a higher degree of exposure to injury.

Accident statistics indicate that the site of most serious and frequent injury in general aviation accidents is the head. In most cases, this is due to lack of restraint, allowing the head to gain momentum during impact and to strike objects in its path with a force exceeding that of the overall crash deceleration. This is especially true in the case of cockpit occupants who face the instrument panel, control wheel and many other injurious environmental structures. Considering these factors, it is practically impossible to avoid contact injuries during crash deceleration when such occupants are not restrained by a properly installed and properly used shoulder harness of adequate strength in combination with a seat belt.

Although seat structure and anchorages meet static strength tie-down requirements, failures frequently occur as a result of dynamic loads imposed by the occupants on seat belts and shoulder harnesses when these are anchored to the seats instead of primary structure. This type of crash force amplification should be taken into consideration when evaluating the dynamic strength of the occupant tie-down chain. Inadequately or improperly secured aircraft equipment and components in the occupiable area also have an injury potential during crash decelerations. Therefore, the tie-down and stowage of such items as luggage, cargo, radio equipment, fire extinguishers and tool boxes requires careful consideration.

OCCUPANTS' ENVIRONMENT

Accident experience has shown that under many impact conditions occupants who are reasonably restrained within a crashworthy structure may still receive injuries through forceful contact with injurious environmental structures, components, etc. (This is particularly true when shoulder harness is not used.) The freedom of movement of the occupant's body during a crash deceleration is governed by the type of restraint system installed and the manner in which it is used. Generally, it can be stated, however, that injuries resulting from the flailing action of the occupant's body show a peripheral trend; that is, the areas farthest away from the seat belt receive most of the injuries (head and lower extremities).

To preclude the probability of injury through striking injurious environment, the limitations of the restraint system should be used as a guide for the extent to which the occupant's environment should be made harmless. The injury potential of all objects and structure within striking range, omni-directionally, can be reduced to a minimum by such measures as elimination of sharp surfaces, safety-type control wheels, breakaway features in instrument panels, use of ductile or energy-absorbing material wherever possible.

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*Approximately 40G transverse to the spine, 25G parallel to the spine (positive G), 15G parallel to the spine (negative G) with due consideration for peak magnitude, duration, rate of onset, and method of body restraint. J.P. Stapp, Human Exposure to Linear Deceleration, Part 2. The Forward-Facing Position and the Development of a Crash Harness. WADC, Wright-Patterson AFB, Ohio, Dec. 1951. A.F.Technical Report No. 5915, Part 2.

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APPENDIX IV

TRANSMISSION OF CRASH FORCE

Another independent injury-producing factor presents itself in the fact that crash forces may be transmitted or even magnified through rigid aircraft structures. This is usually associated with "bottoming out" on structures incapable of absorbing or reducing crash force. Although crash force in most accidents is applied in a direction oblique to the occupant's spine, it is customary to resolve vertical and horizontal components of the crash force resultant and relate these to the human G-force tolerance levels, either parallel or transverse to the spine. A normally seated person, when effectively restrained by a seat belt and shoulder harness, can tolerate (with minimal or no injury) approximately 40 G transverse to the spine, 25 G parallel to the spine in the foot-to-head direction (positive G), 15 G parallel to the spine in the head-to-foot direction (negative G).

Injuries attributed solely to transverse G will seldom be encountered in aircraft accidents, because collapse of structure and/or failure of the restraint system will most likely occur before the limit of transverse G tolerance (40 G) is reached. This is an undesirable situation. Although operational and economic considerations' impose limits on the overall fuselage strength, the occupant tie-down chain should be more compatible in strength with tolerance levels of the body.

Accident experience has shown that injuries directly attributed to the transmission or magnification of crash force are usually associated with predominantly vertical impacts. Vertebral injuries are most often associated with vertical crash force application.

The seat, as the occupant's supporting structure, and the underlying floor structure are the media through which vertical forces are usually transmitted to the occupant. The dynamic response of these media during an impact determines the manner in which the forces acting on the aircraft structure can be modified before reaching the occupant. An extremely rigid structure, which normally is not found in aircraft, would transmit the forces without modification. An elastic structure, which has energy-storing properties, may modify the magnitude and other characteristics of decelerative force to the extent that amplification takes place. For example, a foam rubber cushion (which does not offer an appreciable resistance to compression) allows an occupant to "bottom out" against rigid seat and seat pan structures during a vertical impact. A more desirable situation would be that in which the structure between the occupant and the point of impact had high energy-absorbing characteristics. This may be achieved by the use of structure which collapses progressively without failing suddenly. This ideal form of crash energy absorption results in attenuation of the crash forces transmitted to the occupant. It is one of the basic methods for the incorporation of occupant protection in aircraft design.

POST-CRASH FACTORS

Although a distinction could be made between the prevention of injuries sustained in the dynamic phase of the impact and those sustained in the post-crash events, it is felt that the overall crash survival concept does not allow this distinction. Past experience has shown that accidents involving only very minor impact forces can become catastrophies as a result of post-crash factors.

One of the greatest hazards in an otherwise survivable accident is the possibility of a post-crash fire. These fires, normally, are of a sudden nature and may severely restrict the time available for evacuation. According to a NACA study (Technical Note 2996), not more than 50 seconds may be available for escape in all but the most severe fires, although in some cases passengers must move away from areas of burned-through fuselage in as few as 7-1/2 seconds. This time element becomes even more critical when occupants are handicapped by such factors as disabling injuries, stunned condition, unfamiliarity with the seat belt release or the operation of the emergency exits, being trapped, and panic.

Control of post-crash fires, to some extent, is governed by design (location of fuel cells and fuel lines in relation to electrical and mechanical ignition sources; resistance of fuel system components against rupture under conditions of moderate crash forces or distortion). Other preventive measures include location of fire extinguishers at strategic points and automatic emergency or impact-operated fire extinguishing systems.

In the event of a post-crash fire or a ditching, the ability of all occupants to timely evacuate the aircraft probably becomes the most important survival factor. The evacuation time is a function of the number, location and adequacy of the normal and emergency exits.* The location and emergency operation of normal and emergency exits should be obvious even to the non-experienced passenger. Hand or impact-operated emergency lights can be of vital importance during evacuation in conditions of darkness or subdued light.

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*HIAD (the military Handbook of Instructions for Aircraft Designers) requires "a sufficient number of doors, hatches, and emergency exits to permit complete abandonment of the aircraft in the air, on the ground, or in ditching, in 30 seconds by trained personnel representing the crew and all passengers."

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